ScienceDirect

Contents lists available at sciencedirect.com
Journal homepage: www.elsevier.com/locate/jval

Themed Section

A Systematic Review of Economic Evaluations of COVID-19 Interventions: Considerations of Non-health Impacts and Distributional Issues

Meghan I. Podolsky, BA, Isabel Present, Peter J. Neumann, ScD, David D. Kim, PhD

ABSTRACT

Objectives: This study aims to conduct a systematic review of economic evaluations of COVID-19 interventions and to examine whether and how these studies incorporate non-health impacts and distributional concerns.

Methods: We searched the National Institutes of Health's COVID-19 Portfolio as of May 20, 2021, and supplemented our search with additional sources. We included original articles, including preprints, evaluating both the health and economic effects of a COVID-19–related intervention. Using a pre-specified data collection form, 2 reviewers independently screened, reviewed, and extracted information about the study characteristics, intervention types, and incremental cost-effectiveness ratios (ICERs). We used an Impact Inventory to catalog the types of non-health impacts considered.

Results: We included 70 articles, almost half of which were preprints. Most articles (56%) included at least one non-health impact, but fewer (21%) incorporated non-economic consequences. Few articles (17%) examined subgroups of interest. After excluding negative ICERs, the median ICER for the entire sample (n = 243 ratios) was $67,000/quality-adjusted life-year (QALY) (interquartile range [IQR] $9000-$893,000/QALY). Interventions including a pharmaceutical component yielded a median ICER of $93,000/QALY (IQR $4000-$7,809,000/QALY), whereas interventions including a non-pharmaceutical component were slightly more cost-effective overall with a median ICER of $81,000/QALY (IQR $12,000-$1,034,000/QALY). Interventions reported to be highly cost-effective were treatment, public information campaigns, quarantining identified contacts/cases, canceling public events, and social distancing.

Conclusions: Our review highlights the lack of consideration of non-health and distributional impacts among COVID-19–related economic evaluations. Accounting for non-health impacts and distributional effects is essential for comprehensive assessment of interventions' value and imperative for generating cost-effectiveness evidence for both current and future pandemics.

Keywords: cost-effectiveness analysis, COVID-19, economic evaluations, health equity, systematic review

VALUE HEALTH. 2022; ■(■):■–■

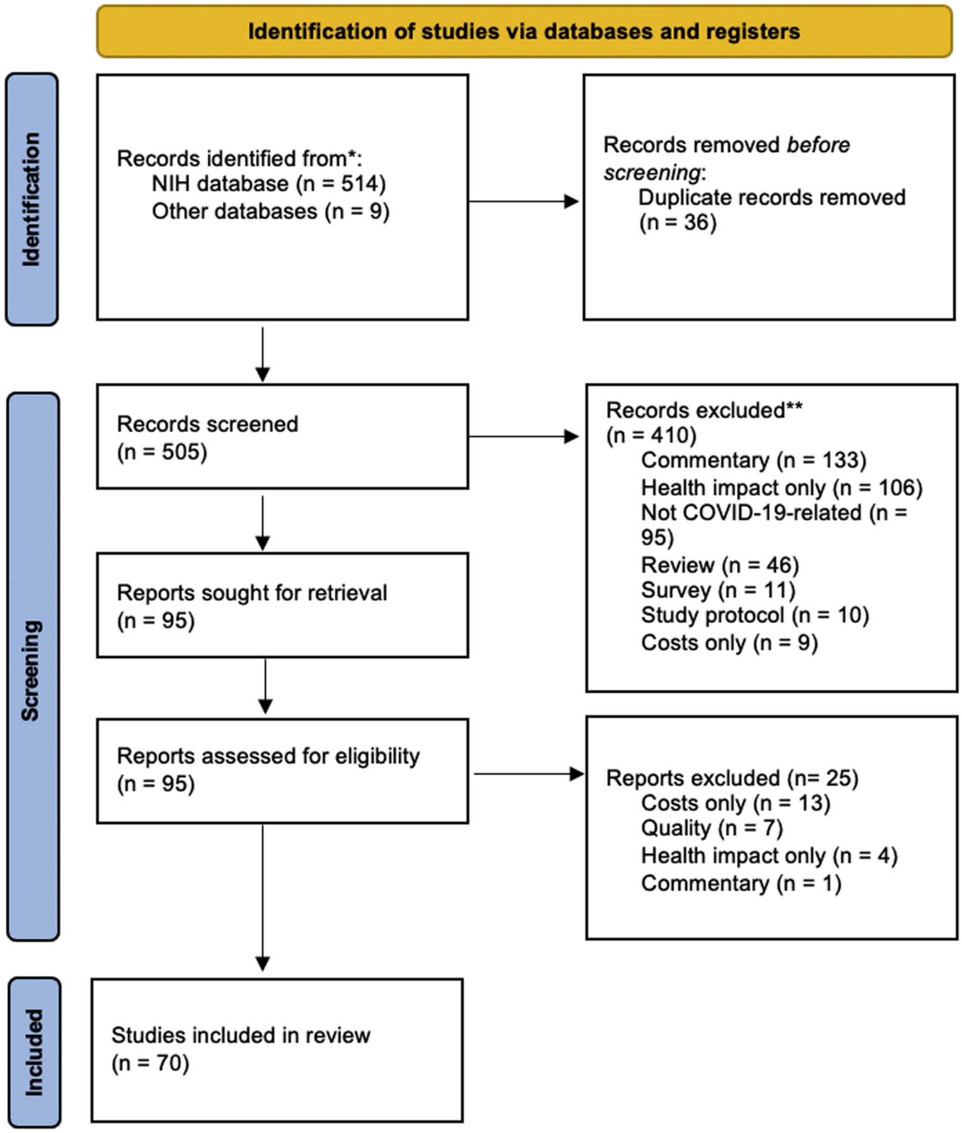
Introduction

Before the arrival of effective vaccines, non-pharmaceutical interventions (NPIs), such as stay-at-home orders, testing, contact tracing, and social distancing, were predominant strategies to prevent the spread of COVID-19.[1-3] Despite concerns regarding their potential long-lasting impacts on mental health, other chronic illnesses, and economic growth[4-6] evidence has suggested that, when effectively implemented, NPIs can reduce COVID-19 incidence and mortality rates as well as protect healthcare system capacity.[7-12]

Questions and uncertainty about trade-offs between health benefits and economic costs associated with NPIs and pharmaceutical interventions highlight the importance of formal economic evaluations to assess their potential value. Non-health impacts, such as lost productivity, can have large effects on these evaluations.[13] In addition, some interventions, such as stay-at-home orders, could worsen existing economic disparities among vulnerable populations, including individuals who cannot work from home and so must either forgo income or risk infection by working.[14-20]

When evaluating the value of a particular intervention, practice guidelines, such as those promulgated by the Second Panel on Cost-Effectiveness in Health and Medicine (hereafter the Second Panel) and the Institute for Clinical and Economic Review in the United States, recognize the importance of capturing relevant impacts on all stakeholders,[13,21,22] yet most economic evaluations before the COVID-19 pandemic did not account for nonhealth impacts.[23,24] There have been systematic reviews of COVID-19 interventions, but many have excluded economic considerations altogether and have not considered the effects of non-health impacts or distributional issues. For example, one review of physical distancing, face masks, and eye protection focused solely on the transmission effects, excluding cost considerations, although they did consider equity impacts.[25] Recently, Dawoud and Soliman conducted a

Figure 1. PRISMA flow diagram.



NIH indicates National Institutes of Health; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

systematic review of published economic evaluations of antiviral treatments for pandemics and found that strategies including these treatments were generally cost-effective.[26] Still, this study also did not catalog non-health or distributional impacts.

We conducted a systematic review of economic evaluations of interventions pertaining to COVID-19 prevention and treatment to examine the extent to which studies included assessment of nonhealth impacts and distributional effects on subgroups. We also evaluated how the consideration of these impacts affected the resulting cost-effectiveness of the intervention.

Methods

Database

We conducted a systematic search of the National Institutes of Health's (NIH) COVID-19 Portfolio, a database updated daily containing articles from PubMed and several preprint servers,[27] to identify relevant economic evaluation studies of COVID-19–related interventions. Due to the emerging state of COVID-19 literature and the increasing use of preprints to disseminate findings (ie, the rate of publication of preprints is ~100 times higher for COVID-19 than other infectious diseases),[28] we included preprints in our sample to capture all available information. We acknowledge that the preprint system has potential limitations because of the lack of peer review to affirm quality, but we conducted informal quality checks of the included articles and excluded those deemed to be of poor quality or lacking sufficient reporting of methods and results, such as model structure, inputs, assumptions, or outcomes. We supplemented our search with additional data sources: National Bureau of Economic Research, EconLit, Google Scholar, and Covid Scholar.[29-32]

Search Strategy

We used the following search words combined using the Boolean "OR" operator: "quality-adjusted life year," "quality-

Table 1. Characteristics of economic evaluation studies for COVID-19.

Study characteristic	# of articles (%) (N = 70)
Date published	
March 2020-July 2020	24 (34)
August 2020-December 2020	22 (31)
January 2021-May 2021	24 (34)
Type of study	
Cost-effectiveness analysis	45 (64)
Cost-benefit analysis	22 (31)
Cost-consequence analysis	3 (4)
Examined differential impacts of the intervention(s) on subgroups	
Yes	12 (17)
Age group (children/elderly)	3 (4)
Healthcare workers	3 (4)
College students	3 (4)
Individuals experiencing homelessness	1 (1)
Diabetic individuals	1 (1)
Race/ethnicity	1 (1)
No	58 (83)
Time horizon	
< 1 year	36 (51)
1-5 years	24 (34)
6-10 years	2 (3)
11+ years	3 (4)
Lifetime	4 (6)
Could not be determined	1 (1)
Country of study	
United States	24 (35)
United Kingdom	10 (15)
Australia	3 (4)
China	3 (4)
India	3 (4)
South Africa	3 (4)
Germany	3 (4)
Sweden	2 (3)
Denmark	2 (3)
Indonesia	2 (3)
Nigeria	2 (3)
Canada	2 (3)
Belgium	1 (1)
Mexico	1 (1)
Morocco	1 (1)
France	1 (1)
Israel	1 (1)
Brazil	1 (1)
Ghana	1 (1)
Pakistan	1 (1)
Turkey	1 (1)
All low- and middle-income countries	1 (1)
Not stated	1 (1)
Funding source	
Government	28 (41)
Not stated	23 (32)
University/academic organization	15 (22)
None	10 (15)
Non-Gates Foundation	9 (13)
Intergovernmental organization	8 (12)
Pharmaceutical/medical device company	5 (7)
Gates Foundation	4 (6)
Professional membership organization	4 (6)
Healthcare organization	2 (3)
Publishing status	
Published in a peer-reviewed journal	37 (53)
Published as a preprint	33 (47)

Continued in the next column

Table 1. Continued

# indicates number.

adjusted life years," "quality adjusted life year," "quality adjusted life years," "quality adjusted life-year," "quality adjusted life-years," "quality-adjusted life-year," "quality-adjusted life-years," "qaly," "qalys," "life year," "life years," "life-year," "life-years," "economic evaluation," "benefit cost," "benefit-cost," "cost benefit," "cost-benefit," "cost effectiveness," and "cost-effectiveness," in search fields DOI, PMID, Title, Abstract, First Author, Last Author, System ID for publication types Journal Article, Meta-Analysis, and Preprint.

A major inclusion criterion was whether identified studies formally conducted evaluations of both costs and health effects of any COVID-19–related intervention. COVID-19–related interventions were not solely limited to medical interventions, but rather included any intervention as categorized in the Oxford COVID-19 Government Response Tracker. We excluded articles pertaining to commentaries, reviews, evaluations of health or economic impacts only, and non–COVID-19 interventions (Fig. 1). We also omitted some articles because of concerns about the quality of the analysis and reporting (n = 7) when articles did not adequately report details of their model structure, inputs, assumptions, or outcomes. Of the 7 articles omitted, 5 were not published in a peer-reviewed journal. To formally assess the quality of the articles included, we completed the Tufts Medical Center Cost-Effectiveness Analysis Registry's 7-point quality scale (see Online Supplement Appendix A in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.02.003). Details of our search are provided in Figure 1.

Two reviewers (M.P. and I.P.) independently screened and reviewed each article, followed by data extraction using a prespecified data collection form (Online Supplement Appendix B in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.02.003). Any discrepancies were resolved through a consensus meeting. Our last search was conducted on May 10, 2021. Although our protocol was not registered, this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (see Online Supplement PRISMA Checklist in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.02.003).

Data Extraction

We collected information on the publication date, publication type (peer-reviewed journal or preprint), type of economic evaluation (cost-effectiveness analysis [CEA], cost-benefit analysis [CBA], or cost-consequence analysis [CCA]), intervention types and descriptions, comparator types and descriptions, time horizon, country of study, funding source(s), summary measure (eg, incremental cost-effectiveness ratios [ICER]), disaggregated outcomes (from CCA), inclusion of nonhealth impacts, and assessment of differential impacts of the intervention(s) on subgroups. It is important to note that there are 2 distinct categories of subgroup analysis: the first being population subgroup analysis,

Table 2. Inclusion of nonhealth impacts in summary outcome measures.

Non-health impact	% of ratios (n)	
	Short term (N = 297)	Long term (N = 285)
Disease/intervention costs	91 (270)	98 (278)
Lost productivity because of illness	49 (147)	37 (106)
GDP	18 (52)	32 (92)
Future consumption unrelated to health	8 (23)	9 (25)
Impact of intervention on educational achievement of population	7 (20)	14 (40)
Change in productivity (absenteeism and presenteeism)	6 (19)	4 (12)
Unpaid caregiver time costs	5 (15)	0
Unrelated healthcare costs	4 (13)	20 (57)
Crimes related to intervention (eg, road accidents)	4 (11)	7 (20)
Production of toxic waste or pollution by intervention	3 (10)	1 (4)
Patient out-of-pocket costs	2 (6)	0
Future related healthcare costs	1 (2)	4 (10)
Uncompensated household production	0 (1)	1 (2)
Employment rate	0 (1)	12 (34)
Patient time costs	0	0
Social services related to intervention	0	0
Cost of intervention on home improvements (eg, removing lead paint)	0	0
Transportation costs	0	7 (19)

GDP indicates gross domestic product.

which stratifies the affected population by risk factors, such as age and preexisting conditions. The second category is equity impact analysis, which stratifies the entire population (including non-recipients) by socioeconomic factors.

To categorize intervention types, we used Oxford's COVID-19 Government Response Tracker categories as a baseline[33] and then added categories as necessary to describe the interventions used in each article (see Online Supplement Appendix C in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.02.003). We collected information on articles' base-case results, excluding sensitivity analyses conducted. Summary outcome measures from non-US studies were converted to 2020 US dollars using the Federal Reserve's foreign exchange rate from December 31, 2020.[34]

Consideration of Non-health Impacts

To describe different costs and impacts included in each evaluation, we amended an Impact Inventory recommended by the Second Panel (see Online Supplement Appendix B in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.02.003), which is based on the modified Impact Inventory for the COVID-19 pandemic we have published elsewhere.[13,35] The non-health impacts we cataloged included caregiver time costs, transportation costs, gross domestic product (GDP) impacts, changes in the employment rate, cost of unpaid lost productivity due to illness, change in productivity (absenteeism presenteesm), cost of uncompensated household production, future consumption unrelated to health, and impacts on non-health sectors, including legal/criminal justice system (eg, social services and number of crimes), education (eg, educational achievement), housing (eg, home improvements), and environment (eg, production of toxic waste or pollution). We also stratified each of these impacts based on the time horizon of analysis—those considered over a period of 1 year or longer were labeled "long term," and otherwise labeled "short term." We conducted an unadjusted regression analysis to determine differences in reporting of non-health impacts among categories of interest.

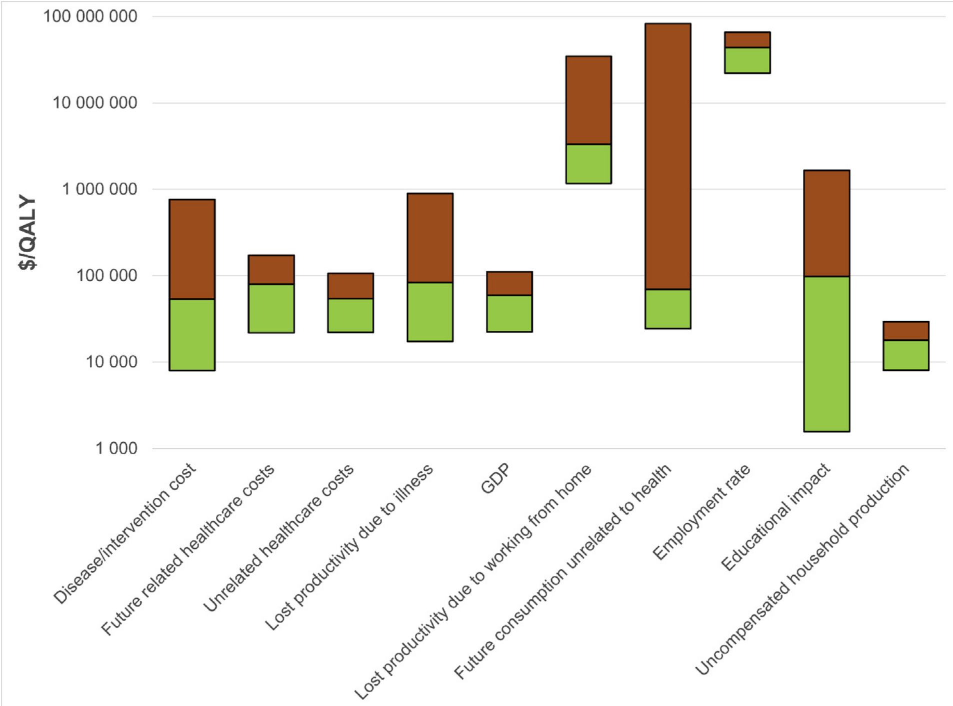
Consideration of Distributional Impacts

We considered an article to account for a distributional impact if it presented a summary outcome measure for any subgroup of individuals (eg, by race-ethnicity, age, sex, preexisting condition, geographic location, occupation [eg, student]) or if the study itself was confined to a defined subgroup. If an article stratified by subgroup in an epidemiologic model (eg, age or risk stratification in an SEIR model), but did not report a summary outcome measure for that subgroup, we did not consider it as having considered the distributional impact.

Analyzing Cost-Effectiveness of COVID-19 Interventions

We aggregated all descriptive data about the articles and recorded the base-case summary measures for each reported combination of intervention(s) and comparator(s). The types of collected cost-effectiveness ratios included $/quality-adjusted life-year (QALY), $/COVID-19 infection averted, $/COVID-19 death averted, $/life-year gained, $/disability-adjusted life-year, and $/health-adjusted life-year. Given the various summary measures reported, we converted $/death averted and $/infection averted to $/QALY based on the recently estimated average QALYs lost per COVID-19 death and infection (0.061 and 0.052, respectively) by

Figure 2. Incremental cost-effectiveness ratios with various nonhealth impacts.



GDP indicates gross domestic product; QALY, quality-adjusted life-year.

Basu and Gandhay,[36] which incorporates both patient and caregiver quality of life. We additionally collected net monetary benefit values reported from CBAs.

Results

Study Characteristics

Among 523 articles identified in our initial search, 70 were included in the final sample (Table 1). Just less than half of the articles included were published as preprints (n = 33, 47%). Most of the articles were CEAs (n = 45, 64%), with the remaining analyses comprising mainly CBAs (n = 22, 31%) and a few CCAs (n = 3, 4%). The most common interventions assessed were testing policies (51% of all ratios), social distancing (35%), stay-at-home requirements (25%), facial coverings (25%), and school closings (25%). The most common funding source was a government organization (41%), with 5 studies funded by a pharmaceutical or medical device company. A total of 32% did not report any funding, but more than two-thirds of the studies without reported funding sources were not yet published in a peer-reviewed journal. There did not appear to be a statistically significant association between the type of intervention studied and the study funder. Notably, of the 12 studies assessing real or hypothetical COVID-19 treatments, only 3 had a pharmaceutical company as a funder. Most used a time horizon shorter than 1 year, and roughly one-half of studies were focused on the United States or the United Kingdom (n = 34, 49%). On average, all articles scored 4.7 on the 7-point quality scale used. Preprint articles scored 0.12 points higher than articles published in peer-reviewed journals, although a 2-sample t test found that this was not a significant difference (P>.05).

Consideration of Nonhealth Impacts

More than one-half of economic evaluations included considered at least one non-health impact (n = 39, 56%). The proportion of articles including non-health impacts was roughly the same by time horizon, whether short term (n = 21, 30%) or long term (n = 18, 26%). Among intervention-specific cost-effectiveness ratios, the most common non-health impacts included were lost productivity because of illness (44%, n = 253 ratios), changes in GDP (25%, n = 144 ratios), education impacts (10%, n = 60 ratios), future consumption (8%, n = 48 ratios), and changes in productivity (absenteeism and presenteeism) (5%, n = 31 ratios) (Table 2). Most of the non-health impacts considered pertained to societal productivity, whereas impacts outside this sector were less frequently estimated (19%, n = 108 ratios). In addition, unadjusted regression analysis found that evaluations of intervention strategies containing a pharmaceutical component are 31.5% more likely to include a non-health impact than evaluations without a pharmaceutical component (P<.001). Cost-effectiveness ratios varied by the type of non-health impact included (Fig. 2).

Consideration of Distributional Issues

Many articles included age-specific estimates for COVID-19 death or negative outcomes, such as hospitalizations or complications, in their underlying epidemiologic models, but only 12 (17%) assessed the cost-effectiveness of interventions for non-age specific subgroups. A total of 9 (12%) articles evaluated the impact of COVID-19 interventions across different age or occupation groups, such as the elderly and children,[37-39] healthcare workers,[40-42] or college students.[43-45] Nevertheless, only 3 examined other subgroups, such as individuals experiencing homelessness,[46] diabetic individuals,[47] and those of different race/

Table 3. Relative cost-effectiveness of strategies including selected intervention types.

Intervention type	$/QALY		
	Median (N = 243)	Interquartile range	N
Treatment	26,000	6000-1,057,000	48 ratios; 8 articles
Quarantine identified contacts	40,000	27,000-49,000	28 ratios; 2 articles
Public information campaigns	40,000	5-802,000	16 ratios; 5 articles
Cancel public events	41,000	27,000-63,000	30 ratios; 2 articles
Quarantine identified cases	43,000	17,000-174,000	122 ratios; 6 articles
Social distancing	49,000	26,000-408,000	97 ratios; 10 articles
All nonpharmaceutical interventions (excluding vaccination and therapeutics)	81,000	12,000-1,034,000	302 ratios; 28 articles
School closing	89,000	38,000-968,000	48 ratios; 4 articles
Vaccination policy	94,000	3000-132,837,000	45 ratios; 5 articles
Emergency investment in healthcare	101,000	2000-3,111,000	46 ratios; 6 articles
Testing policy	117,000	9000-1,164,000	185 ratios; 15 articles
Screening	172,000	14,000-4,522,000	50 ratios; 5 articles
Facial coverings	694,000	42,000-3,111,000	100 ratios; 9 articles
Proper hand hygiene	1,023,000	37,000-2,255,000	24 ratios; 4 articles
Cleaning	1,260,000	214,000-2,480,000	23 ratios; 2 articles
Stay-at-home requirements	30,433,000	788,000-141,298,000	30 ratios; 6 articles

Note. Listed in order of decreasing cost-effectiveness using $/QALY values. Values rounded to nearest thousand. Interventions where there were >15 values in the data set for $/QALY ratios included.
QALY indicates quality-adjusted life-year.

ethnicity.[48] Evaluations of intervention strategies including a pharmaceutical component were 1% more likely to include a non-health impact than evaluations without a pharmaceutical component ($P<.05$).

Cost-Effectiveness Evidence

Of the 70 identified studies, 582 intervention-specific summary outcome measures were reported with substantial variations. The 45 CEAs reported 426 intervention-specific cost-effectiveness ratios, including $/QALY (161, 28% overall), $/infection averted (142, 24%), $/death averted (46, 8%), $/life-year gained (44, 8%), $/disability-adjusted life-year (16, 3%), $/health-adjusted life-year (15, 3%), and $/equal value life-year gained (2, < 1%). Twenty-two CBAs reported 117 net monetary benefit measures (20%) and 4 values (< 1%) were measures of net health benefit using wellbeing-years. Notably, 3 CCA articles reported their outcomes in a disaggregated format (eg, GDP loss, total population deaths, federal receipts, testing costs).

After excluding negative ICERs, which indicates either dominated (ie, intervention is less effective and more costly) or health improving and cost-saving, the sample had 243 $/QALY ratios. Of those ratios, the overall median ICER was $67,000/QALY (interquartile range [IQR] $9000-$893,000/QALY). Interventions including a nonpharmaceutical component had a median ICER of $81,000/QALY (IQR $12,000-$1,034,000/QALY), whereas interventions including a pharmaceutical component reported a median ICER of $93,000/QALY (IQR $4000-$7,809,000/QALY). Conducting a Mann-Whitney test using a normal approximation found a $P=.19$, indicating that the difference between the 2 samples was not significant. We conducted the test again omitting interventions that contained both nonpharmaceutical and pharmaceutical components, to ensure that these overlapping ratios were not driving the result, and the result remained unchanged ($P=.14$). Interventions reported to be highly cost-effective were treatment, public information campaigns, quarantining identified contacts/cases, canceling public events, and social distancing (Table 3).

Discussion

Our review of economic evaluations of COVID-19 interventions found that just more than half of the identified economic evaluations included non-health impacts, whereas most did not evaluate distributional effects. In addition, the analytic time horizon tended to be short. These shortcomings highlight that many of these evaluations may not fully capture relevant and important consequences of the COVID-19 interventions.[13,49,50] There was substantial heterogeneity in the interventions studied and outcome measures reported, which made inter-study comparison difficult.

The proportion of economic evaluations that included a non-health impact for COVID-19 interventions (56%) was greater than in the overall CEA literature (15%),[23] signaling the importance of capturing substantial non-health impacts of COVID-19. Still, challenges remain in identifying and quantifying non-health impacts. One of the key difficulties is the lack of data available to quantify these impacts.[23,51,52] Attempting to generalize estimates of impacts outside the scope of the disease or population could introduce greater uncertainty. As more data, such as the effects on economic indicators,[53-55] education,[56-58] and the environment,[59-61] become available, future studies of COVID-19 or other diseases with potentially large societal impacts might be able to incorporate estimates with greater precision.

The lack of consideration for non-health impacts of interventions could lead to an incomplete assessment of an intervention's value and potentially result in a misallocation of healthcare resources. For example, when assessing the trade-offs between health benefits and economic impacts of a stay-at-home order during a pandemic, it would be important to consider an intervention's broader impact, such as educational attainment, increases in unemployment, and decreases in productivity while working from home, to provide a comprehensive picture of the trade-offs associated with such intervention. Similarly, despite its own guidelines stating that the societal perspective should be presented as a co-basecase with the health sector perspective when the impact on nonhealth factors is substantial, the Institute for Clinical and Economic Review's evaluation of remdesivir for COVID-19 did not include any non-health impacts.[21,62,63]

In addition, vulnerable populations (eg, individuals with more chronic conditions, those of economic disadvantage, and people of color) are more likely to experience adverse outcomes because of COVID-19. Nevertheless, our review found that most of the economic evaluations only reported summary outcomes at a population level. In addition, although a handful of studies reported summary measures stratified by age groups, only 2 focused specifically on vulnerable populations, such as racial and ethnic minoirities[48] or individuals experiencing homelessness,[46] and none of the reviewed articles conducted distributional equity impact analysis. The dearth of distributional analyses is likely because of a lack of concrete estimates of the economic impacts of different initiatives on subgroups of interest, yet it is important to generate cost-effectiveness information for specific populations of interest to guide better policy decisions and implement targeted interventions to help the most vulnerable populations.[64,65]

Researchers should also strive to better align evaluations with the populations that are disproportionately impacted.[50,66] Recent reviews have found that factoring in distributional effects resulted in more favorable cost-effectiveness profiles in more than three-quarters of cases and have indicated that the field is beginning to recognize the importance of capturing equity and distributive considerations through distributional CEA.[67,68] For example, vaccines have historically fallen in this category because of their large health gains and potential to lift children out of poverty by enabling them to avoid potentially fatal infectious diseases and therefore grow up and become economically productive.[69]

Our analysis has some limitations. Although we included international literature in our review, most included articles came from high-income countries, and we did not include non–English language studies. Our sample contained a high proportion of preprints, because of the emerging state of COVID-19 literature, which may vary in terms of study quality. A recent systematic review of preprints assessing the quantitative impact of COVID-19 interventions (though also a preprint) found that the literature failed to meet the criteria for causal inference.[70] In addition, in converting the different summary outcome measures to $/QALY, we used a standardized value of an averted infection or death for a "representative US resident," although the model used to generate this estimate did account for age-stratification of the severity of infection and likelihood of long-term consequences (acute kidney injury).[36] We recognize the importance of using subgroup-specific QALY estimates and encourage future researchers to invest in estimating these values for COVID-19. These conversions are blunt metrics and are not meant to be definitive, but rather an illustrative exercise. Our sample largely did not present estimates of summary outcome measures stratified by subgroup.

Conclusions

This systematic review of COVID-19–related economic evaluations highlights the lack of consideration of nonhealth and distributional impacts. Accounting for broad nonhealth impacts and distributional effects is essential for a comprehensive assessment of interventions' value and imperative for generating cost-effectiveness evidence not only for the current pandemic but future ones.

Supplemental Materials

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jval.2022.02.003.

Article and Author Information

Accepted for Publication: February 1, 2022

Published Online: xxxx

doi: https://doi.org/10.1016/j.jval.2022.02.003

Author Affiliations: Center for the Evaluation of Value and Risk in Health, Institute for Clinical Research and Health Policy Studies, Tufts Medical Center, Boston, MA, USA (Podolsky, Present, Neumann, Kim); Department of Medicine, Tufts University School of Medicine, Boston, MA, USA (Neumann, Kim).

Correspondence: David D. Kim, PhD, Center for the Evaluation of Value and Risk in Health, Institute for Clinical Research and Health Policy Studies, Tufts Medical Center, 800 Washington St, Box 063, Boston, MA 02111, USA. Email: dkim3@tuftsmedicalcenter.org

Author Contributions: *Concept and design:* Kim
Acquisition of data: Podolsky, Present
Analysis and interpretation of data: Podolsky, Present, Kim
Drafting of the manuscript: Podolsky
Critical revision of the paper for important intellectual content: Podolsky, Present, Neumann, Kim
Statistical analysis: Podolsky
Obtaining funding: Kim
Administrative, technical, or logistic support: Neumann, Kim
Supervision: Neumann, Kim

Conflict of Interest Disclosures: All authors reported receiving grants from Pharmaceutical Research and Manufacturers of America (PhRMA) during the conduct of the study. Ms Podolsky reported receiving grants from RA Capital outside the submitted work. Dr Neumann reported consulting for Precision HEOR and Sarepta; reported serving on the advisory board for the Congressional Budget Office; reported receiving funds from the Cost-Effectiveness Analysis Registry sponsors (the Cost-Effectiveness Analysis Registry has been funded by the National Science Foundation, National Library of Medicine, Agency for Healthcare Research and Quality, the Centers for Disease Control, and a variety of pharmaceutical and device companies who subscribe to the data); reported receiving grants from Amgen, the Gates Foundation, Bristol Myers Squibb, the National Pharmaceutical Council, the Alzheimer's Association, National Institutes of Health, and Arnold Ventures; and reported being on advisory boards for Biogen, the PhRMA Foundation, Avexis, Intercept, Bayer, Amgen, Cytokinetics, Sanofi, Merck, ArgenX, Novartis and Panalogo outside the submitted work. Dr Kim reported receiving grants from Arnold Ventures and the National Institutes of Health/National Heart, Lung, and Blood Institute, personal fees from the American College of Physicians and Panalgo outside the submitted work. No other disclosures were reported.

Funding/Support: This study was funded by the Pharmaceutical Research and Manufacturers of America (PhRMA).

Role of the Funder/Sponsor: The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES

1. Wu KJ, Zimmer C, Corum J. Coronavirus drug and treatment tracker. The New York Times. https://www.nytimes.com/interactive/2020/science/coronavirus-drugs-treatments.html. Accessed May 10, 2021.
2. Outpatient management of acute COVID-19. COVID-19 Treatment Guidelines Web site. National Institutes of Health. https://www.covid19treatmentguidelines.nih.gov/outpatient-management/. Accessed May 10, 2021.
3. Holder J. Tracking coronavirus vaccinations around the world. The New York Times. https://www.nytimes.com/interactive/2021/world/covid-vaccinations-tracker.html. Accessed May 10, 2021.
4. Haesebaert F, Haesebaert J, Zante E, Franck N. Who maintains good mental health in a locked-down country? A French nationwide online survey of 11,391 participants. *Health Place*. 2020;66:102440.
5. Gloster AT, Lamnisos D, Lubenko J, et al. Impact of COVID-19 pandemic on mental health: an international study. *PLoS One*. 2020;15(12):e0244809.
6. Ma S, Kim DD, Cohen JT, Neumann PJ. Measuring "fearonomic effects" in valuing therapies: an application to COVID-19 in China. *Value Health*. 2020;23(11):1405–1408.
7. Lau H, Khosrawipour V, Kocbach P, et al. The positive impact of lockdown in Wuhan on containing the COVID-19 outbreak in China. *J Travel Med*. 2020;27(3):taaa037.
8. Alfano V, Ercolano S. The efficacy of lockdown against COVID-19: a cross-country panel analysis. *Appl Health Econ Health Policy*. 2020;18(4):509–517.
9. Brauner JM, Mindermann S, Sharma M, et al. Inferring the effectiveness of government interventions against COVID-19. *Science*. 2021;371(6531):eabd9338.
10. Haug N, Geyrhofer L, Londei A, et al. Ranking the effectiveness of worldwide COVID-19 government interventions. *Nat Hum Behav*. 2020;4(12):1303–1312.
11. Pachetti M, Marini B, Giudici F, et al. Impact of lockdown on Covid-19 case fatality rate and viral mutations spread in 7 countries in Europe and North America. *J Transl Med*. 2020;18(1):338.
12. Rezapour A, Souresrafil A, Peighambari MM, Heidarali M, Tashakori-Miyanroudi M. Economic evaluation of programs against COVID-19: a systematic review. *Int J Surg*. 2021;85:10–18.
13. Kim DD, Neumann PJ. Analyzing the cost effectiveness of policy responses for COVID-19: the importance of capturing social consequences. *Med Decis Making*. 2020;40(3):251–253.
14. Batchlor E. Were COVID-19 patients in the wrong hospital—or the wrong community? What really drove COVID-19 outcomes in South Los Angeles. Health Affairs Blog. https://www.healthaffairs.org/do/10.1377/forefront.20210430.501118/full/. Accessed September 20, 2020.
15. Polyakova M, Udalova V, Kocks G, Genadek K, Finlay K, Finkelstein AN. Racial disparities in excess all-cause mortality during the early COVID-19 pandemic varied substantially across states. *Health Aff (Millwood)*. 2021;40(2):307–316.
16. Gross CP, Essien UR, Pasha S, Gross JR, Wang Sy, Nunez-Smith M. Racial and ethnic disparities in population-level Covid-19 mortality. *J Gen Intern Med*. 2020;35(10):3097–3099.
17. Price-Haywood EG, Burton J, Fort D, Seoane L. Hospitalization and mortality among Black patients and White patients with Covid-19. *N Engl J Med*. 2020;382(26):2534–2543.
18. Wadhera RK, Wadhera P, Gaba P, et al. Variation in COVID-19 hospitalizations and deaths across New York City boroughs. *JAMA*. 2020;323(21):2192–2195.
19. Vanjani R, Martino S, Wunsch C. Health equity during COVID-19. *J Gen Intern Med*. 2020;35(10):3067–3068.
20. Yancy CW. COVID-19 and African Americans. *JAMA*. 2020;323(19):1891–1892.
21. 2020-2023 value assessment framework. Institute for Clinical and Economic Review. https://icer.org/wp-content/uploads/2020/10/ICER_2020_2023_VAF_102220.pdf. Accessed January 15, 2021.
22. Neumann PJ, Sanders GD, Basu A, et al. Recommendations on perspectives for the reference case. In: Neumann PJ, Sanders GD, Russell LB, Siegel JE, Ganiats TG, eds. *Cost-Effectiveness in Health and Medicine*. 2nd ed. New York, NY: Oxford University Press; 2017:69.
23. Kim DD, Silver MC, Kunst N, Cohen JT, Ollendorf DA, Neumann PJ. Perspective and costing in cost-effectiveness analysis, 1974-2018 [published correction appears in Pharmacoeconomics. 2020 Dec;38(12):1377. *Pharmacoeconomics*. 2020;38(10):1135–1145.
24. Desai K, Druyts E, Yan K, Balijepalli C. On pandemic preparedness: how well is the modelling community prepared for COVID-19? *Pharmacoeconomics*. 2020;38(11):1149–1151.
25. Chu DK, Akl EA, Duda S, et al. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. *Lancet*. 2020;395(10242):1973–1987.
26. Dawoud DM, Soliman KY. Cost-effectiveness of antiviral treatments for pandemics and outbreaks of respiratory illnesses, including COVID-19: a systematic review of published economic evaluations. *Value Health*. 2020;23(11):1409–1422.
27. iSearch COVID-19 Portfolio. National Institutes of Health. https://icite.od.nih.gov/covid19/search/. Accessed May 20, 2021.
28. Brierley L. Lessons from the influx of preprints during the early COVID-19 pandemic. *Lancet Planet Health*. 2021;5(3):e115–e117.
29. National Bureau of Economic Research. http://nber.org/. Accessed November 13, 2020.
30. EconLit. American Economic Association. https://www.aeaweb.org/econlit/. Accessed November 12, 2020.
31. Google Scholar Google. https://scholar.google.com/. Accessed May 13, 2021.
32. COVID Scholar. https://covidscholar.org/. Accessed May 10, 2021.
33. Hale T, Anania J, Angrist N, et al. Variation in government responses to COVID-19. University of Oxford, Blavatnik School of Government. https://www.bsg.ox.ac.uk/research/publications/variation-government-responses-covid-19. Accessed August 8, 2020.
34. Foreign exchange rates — H.10 weekly. Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/releases/h10/20210104/. Accessed May 21, 2021.
35. Salomon JA, Trikalinos TA, Sanders GD, Mandelblatt JS. Identifying and quantifying the consequences of interventions. In: Neumann PJ, Sanders GD, Russell LB, Siegel JE, Ganiats TG, eds. *Cost-Effectiveness in Health and Medicine*. 2nd ed. New York, NY: Oxford University Press; 2017.
36. Basu A, Gandhay VJ. Quality-adjusted life-year losses averted with every COVID-19 infection prevented in the United States. *Value Health*. 2021;24(5):632–640.
37. Blakely T, Bablani L, Carvalho N, et al. Integrated quantification of the health and economic impacts of differing strategies to control the COVID-19 pandemic. Preprint. Posted online June 17, 2020. SSRN. https://doi.org/10.2139/ssrn.3605136.
38. Brotherhood L, Kircher P, Santos C, Tertilt M. An economic model of the COVID-19 epidemic: the importance of testing and age-specific policies. IZA Institute of Labor Economics. https://docs.iza.org/dp13265.pdf. Accessed October 25, 2020.
39. Stein N, Moore R. Closing schools for COVID-19: a cost–benefit analysis. Scioto Analysis. https://static1.squarespace.com/static/5bdb6f642714e55b84ebe507/t/5ef0e19b03e56c3a4a905c46/1592844726518/schoolclsing.pdf. Accessed December 12, 2020.
40. Risko N, Werner K, Offorjebe OA, Vecino-Ortiz AI, Wallis LA, Razzak J. Cost-effectiveness and return on investment of protecting health workers in low- and middle-income countries during the COVID-19 pandemic. *PLoS One*. 2020;15(10):e0240503.
41. Savitsky LM, Albright CM. Preventing COVID-19 transmission on labor and delivery: a decision analysis. *Am J Perinatol*. 2020;37(10):1031–1037.
42. Ebigbo A, Römmele C, Bartenschlager C, et al. Cost-effectiveness analysis of SARS-CoV-2 infection prevention strategies including pre-endoscopic virus testing and use of high risk personal protective equipment. *Endoscopy*. 2021;53(2):156–161.
43. Paltiel AD, Zheng A, Walensky RP. Assessment of SARS-CoV-2 screening strategies to permit the safe reopening of college campuses in the United States. *JAMA Netw Open*. 2020;3(7):e2016818.
44. Losina E, Leifer V, Millham L, et al. College campuses and COVID-19 mitigation: clinical and economic value. *Ann Intern Med*. 2021;174(4):472–483.
45. Zafari Z, Goldman L, Kovrizhkin K, Muennig P. The cost-effectiveness of common strategies for the prevention of transmission of SARS-CoV-2: a flexible policy online platform. Preprint. Posted online September 16, 2020. MedRxiv. https://doi.org/10.1101/2020.08.13.20166975.
46. Baggett TP, Scott JA, Le MH, et al. Clinical outcomes, costs, and cost-effectiveness of strategies for adults experiencing sheltered homelessness during the COVID-19 pandemic. *JAMA Netw Open*. 2020;3(12):e2028195.
47. Omame A, Sene N, Nometa I, et al. Analysis of COVID-19 and comorbidity co-infection model with optimal control [published online June 2, 2021]. *Optim Control Appl Methods*. https://doi.org/10.1002/oca.2748.
48. Doti JL. Benefit-cost analysis of COVID-19 policy intervention at the state and national level. Economics Faculty Articles and Research, Chapman University. https://digitalcommons.chapman.edu/economics_articles/257/.
49. Kim DD, Wilkinson CL, Pope EF, Chambers JD, Cohen JT, Neumann PJ. The influence of time horizon on results of cost-effectiveness analyses. *Expert Rev Pharmacoecon Outcomes Res*. 2017;17(6):615–623.
50. Cookson R, Mirelman AJ, Griffin S, et al. Using cost-effectiveness analysis to address health equity concerns. *Value Health*. 2017;20(2):206–212.
51. Jiao B, Basu A. Catalog of age- and medical condition-specific healthcare costs in the United States to inform future costs calculations in cost-effectiveness analysis. *Value Health*. 2021;24(7):957–965.
52. Neumann PJ, Kim DD, Trikalinos TA, et al. Future directions for cost-effectiveness analyses in health and medicine. *Med Decis Making*. 2018;38(7):767–777.
53. Berardi C, Antonini M, Genie MG, et al. The COVID-19 pandemic in Italy: policy and technology impact on health and non-health outcomes. *Health Policy Technol*. 2020;9(4):454–487.
54. Ashraf BN. Economic impact of government interventions during the COVID-19 pandemic: international evidence from financial markets. *J Behav Exp Finance*. 2020;27:100371.
55. Huang A, Makridis C, Baker M, Medeiros M, Guo Z. Understanding the impact of COVID-19 intervention policies on the hospitality labor market. *Int J Hosp Manag*. 2020;91:102660.
56. Sintema EJ. Effect of COVID-19 on the performance of Grade 12 students: implications for STEM education. *Eurasia J Math Sci Tech Ed*. 2020;16(7):em1851.
57. Marinoni G, van't Land H, Jensen T. THE impact of COVID-19 on higher education around the world: IAU global survey report. International Association

of Universities. https://www.iau-aiu.net/IMG/pdf/iau_covid19_and_he_survey_report_final_may_2020.pdf. Accessed April 3, 2021.
58. Upoalkpajor J-LN, Upoalkpajor CB. The impact of COVID-19 on education in Ghana. *Asian J Educ Soc Stud*. 2020;9(1):23–33.
59. Benson NU, Bassey DE, Palanisami T. COVID pollution: impact of COVID-19 pandemic on global plastic waste footprint. *Heliyon*. 2021;7(2):e06343.
60. Mostafa MK, Gamal G, Wafiq A. The impact of COVID 19 on air pollution levels and other environmental indicators — a case study of Egypt. *J Environ Manag*. 2021;277:111496.
61. Tanzer-Gruener R, Li J, Eilenberg SR, Robinson AL, Presto AA. Impacts of modifiable factors on ambient air pollution: a case study of COVID-19 shutdowns. *Environ Sci Technol Lett*. 2020;7(8):554–559.
62. Alternative pricing models for remdesivir and other potential treatments for COVID-19. Institute for Clinical and Economic Review. http://icer.org/wp-content/uploads/2020/11/ICER-COVID_Updated_Report_11102020.pdf. Accessed January 18, 2021.
63. Institute for Clinical and Economic Review. ICER's reference case for economic evaluations: principles and rationale. https://icer.org/wp-content/uploads/2020/10/ICER_Reference_Case_013120.pdf. Accessed February 14, 2021.
64. Espinoza MA, Manca A, Claxton K, Sculpher MJ. The value of heterogeneity for cost-effectiveness subgroup analysis: conceptual framework and application. *Med Decis Making*. 2014;34(8):951–964.
65. Stevens W, Normand C. Optimisation versus certainty: understanding the issue of heterogeneity in economic evaluation. *Soc Sci Med*. 2004;58(2):315–320.
66. Glover RE, van Schalkwyk MCI, Akl EA, et al. A framework for identifying and mitigating the equity harms of COVID-19 policy interventions. *J Clin Epidemiol*. 2020;128:35–48.
67. Avanceña ALV, Prosser LA. Examining equity effects of health interventions in cost-effectiveness analysis: a systematic review. *Value Health*. 2021;24(1):136–143.
68. Johri M, Norheim OF. Can cost-effectiveness analysis integrate concerns for equity? Systematic review. *Int J Technol Assess Health Care*. 2012;28(2):125–132.
69. Cookson R, Griffin S, Norheim OF, Culyer AJ, Chalkidou K. Distributional cost-effectiveness analysis comes of age. *Value Health*. 2021;24(1):118–120.
70. Haber NA, Clarke-Deelder E, Feller A, et al. Problems with evidence assessment in COVID-19 health policy impact evaluation (PEACHPIE): a systematic review of study design and evidence strength. Preprint. Posted online September 10, 2021. MedRxiv. https://doi.org/10.1101/2021.01.21.21250243.